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# A New Seismic Data System for Determining Nuclear Test Yields At the Nevada Test Site

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Prepared by
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# A New Seismic Data System for Determining Nuclear Test Yields At the Nevada Test Site

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**Abstract**

An important capability in conducting underground nuclear tests is to be able to determine the nuclear test yield accurately within hours after a test. Due to a nuclear test moratorium, the seismic method that has been used in the past has not been exercised since a non-proliferation high explosive test in 1993. Since that time, the seismic recording system and the computing environment have been replaced with modern equipment. This report describes the actions that have been taken to preserve the capability for determining seismic yield, in the event that nuclear testing should resume. Specifically, this report describes actions taken to preserve seismic data, actions taken to modernize software, and actions taken to document procedures. It concludes with a summary of the current state of the data system and makes recommendations for maintaining this system in the future.

## Acknowledgements

Thanks to Doug Garbin of Sandia National Laboratories for his knowledgeable guidance throughout this project based on years of experience being the scientific advisor for determining nuclear yield during nuclear tests.

My thanks also to Doug Seastrand (formerly of Bechtel Nevada), who helped me to understand the legacy system that preceded this work.

Also, I thank Bob White of Bechtel for supplying me with all the legacy data that was converted and for providing me with samples of new seismic data and the specifications for reading it.

And although it was a separate project, we all owe Gary Vines (a retired Bechtel contractor) a debt of gratitude for selectively digitizing data from analog tapes and collecting the historical seismic field sheets that made it possible for us to augment our system. Curtis Harmon, a student intern, assisted me in making this data available online.

Finally, I thank Al Chabai, Christopher Deeney, and Doug Garbin (all of Sandia National Laboratories) for their insightful comments in reviewing this report.

# Contents

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## Summary

An important capability associated with underground nuclear tests is to be able to determine the nuclear yield accurately within hours after a test. Because hydrodynamic and radiochemistry techniques take longer to complete, a seismic method has historically been the technique of choice. This technique involves comparing seismic data recorded during the test to selected seismic data from previous tests of a known yield. Due to a nuclear test moratorium, this seismic method has not been exercised since a non-proliferation high explosive test in 1993.

In the event that nuclear testing should resume, new personnel will likely perform this task for the first time using all new seismic recording equipment and a different computing environment. To prepare for this possibility, steps have been taken to move the historical seismic data to a modern Windows® 2000 server, modernize the software, and document the procedure for determining nuclear yield in this new environment.

During the conversion of the seismic data, a systematic validation and correction process greatly improved the data integrity. The seismic database and waveform files are now stored in internally documented formats to reduce the likelihood of information loss.

A Windows-based application, *Seismosaic*, has been developed to replace the VAX™ software that was previously used to determine seismic yield. *Seismosaic* retains the basic functionality of the VAX™ software, but with totally redesigned user and data interfaces.

The new system has not been exercised completely by any real test conditions. It would be prudent to do so, if a significant seismic event should occur in the near future.


# Statement of Problem

In the event that nuclear testing should resume, is Sandia ready to determine the nuclear yield in a timely manner? Specifically, is the seismic method that was used on previous tests compatible with current seismic and computer technology and is the method clearly documented and understood by those who will have to perform this task in the future for the first time? Furthermore, is this large seismic data repository (collected over decades of nuclear testing) conveniently available for possible new applications?

# Background

Approximately 800 underground nuclear tests were conducted at the Nevada Test Site (NTS) from 1951 to 1992. Since at least the early 1960's, a good estimate of the nuclear yield was established on "shot" day by comparing seismic data taken during the test with selected seismic data from previous related tests of a known yield. The seismic data was recorded on the "Leo Brady Seismic Network" – named for the man who was primarily responsible for maintaining the network and determining the nuclear yield during nuclear tests. (See Figure 1.) Historically, the network was located at 5 stations that encircle the Nevada Test Site at ranges of a few hundred kilometers. Today 3 of these stations and a new one at Marysvale, UT are used to record earthquakes and chemical explosions in the region for the U. S. Geological Survey (USGS).

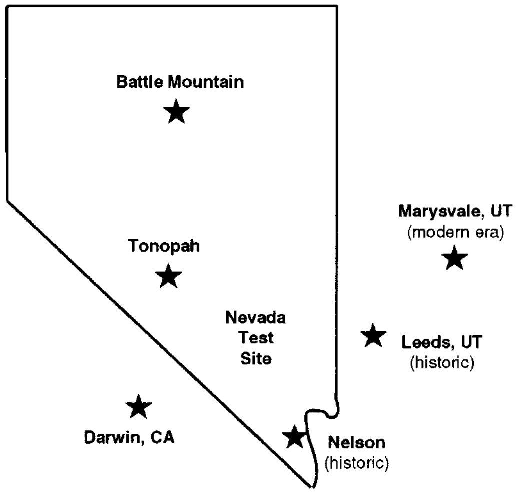



**Figure 1. Leo Brady Seismic Network**

In the early days, sets of calibration curves for different areas were maintained and updated as new tests were executed. Over time, as technology improved and records were moved from file cabinets to computers, the procedure for determining nuclear yield became more automated. From the 1980's until testing ended in 1992, both the seismic data and the software tools that were developed for this procedure were located on a VAX™ computer.

The procedure for determining nuclear yield was last exercised with these tools by Doug Garbin on a non-proliferation high-explosive experiment in 1993. Doug had done selected tests prior to that, as the scientific advisor to Leo Brady. With Leo's untimely death in 1993 and Doug's impending retirement, there is a worrisome lack of depth in qualified personnel. To magnify the situation, since 1993, the seismic recording equipment has been replaced and the VAX™ computer is no longer in service.

In January 1999, a project was initiated to ensure that the capability that existed in 1993 will still be available in the future despite these changes in technology and personnel. The project consisted of two primary parts. The first part was to convert the seismic data and related software to a modern architecture. The second part was to provide a manual that describes how to use the new system to determine test yields. This is the final report on that project.

# Actions Taken to Preserve Seismic Data

There are three categories of seismic data that were kept on the VAX™. They are the properties database, the waveform files, and the amplitudes files.

The properties database contains geological information pertaining to the detonation source such as location, depth of burial, water level, density, saturation, porosity, etc.

The waveform files contain the seismic waveforms that were recorded during events. (*Event* is a seismic term that indicates significant seismic activity for a certain period of time. It should not be confused with the term *test*, which is a specific type of seismic event, namely a nuclear test. The term *event* should not be used to refer to either a test or a detonation. However, one or more tests consisting of one or more detonations will occur during the waveform-recording period that is designated an event.)

Prior to 1983, waveforms were recorded on analog tape. Waveforms were recorded digitally for the first time in 1983. Approximately 10% of the pre-1983 analog waveforms have been digitized and are now available online. These recently digitized waveforms are primarily from high-yield tests.

The amplitudes files contain amplitudes that were measured at the first arrival of the P-wave. (See Figure 2.) The P-wave is used because it is more representative of an explosion than the shear wave and because its early arrival is free from interference from the later-arriving signals. Prior to 1983, amplitudes were measured manually from strip charts. In later years the amplitudes were measured from digitized waveforms by interactive computer graphics. These amplitudes are used in least-squares techniques to determine the yield.[1]

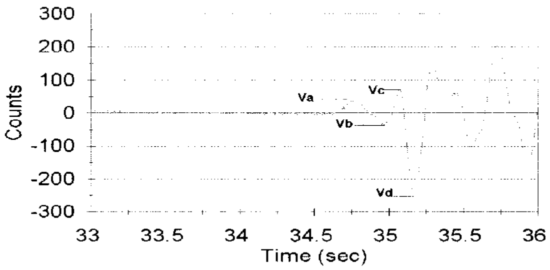



**Figure 2. P-wave Amplitudes**

All of the data on the VAX™ has now been moved to a Windows® 2000 server and has also been converted to more readable formats that are less likely to be corrupted. In addition, the properties database has been expanded to include information that was not available on the VAX™. (See Appendix A for a more detailed description of the database.)

Throughout all the conversion steps, an extensive effort was made to systematically search for, validate, and correct data anomalies. This was done by programmatically comparing data in the database with data in the headers of the waveform and amplitudes files. As a result of these actions, the integrity of the seismic data is now greatly improved. (See Appendix B for a more detailed description of the conversion and data validation process.)

A summary of the data that now resides on the Windows® 2000 server is shown below in Figure 3. Note that we only have properties, digitized waveforms, and amplitudes for approximately 12% of the events in the years 1966-1968. We have properties and amplitudes for virtually all the events in the years 1969-1982, but we only have digitized waveforms for approximately 10% of the events in those years. We have a complete set of data for all 137 events in the years 1983-1993 except for a few missing properties.

| | **Events** | **Waveforms** | **Amplitudes** |
|---|---|---|---|
| **1966-1968** | 18 | 201 | 541 |
| **1969-1982** | 343 | 248 | 13726 |
| **1983-1993** | 137 | 3141 | 6166 |
| **Total** | 498 | 3590 | 20433 |

**Figure 3. Seismic Test Data**

The properties database is well populated from 1971 to 1992, but it is missing many properties in the years 1966-1970. A spot check of the Containment Evaluation Panel (CEP) documents at the U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office showed that most of these properties were not available there either, which would indicate that either they were never measured or we have yet to discover the primary source for CEP properties. It was not considered cost-effective to pursue a search for additional properties at this time.

# Actions Taken to Modernize Software

A Windows-based application, *Seismosaic*, has been developed to replace the VAX™ software. *Seismosaic* was developed using Visual C++. Although the user interface is much different in *Seismosaic*, the basic functionality of the VAX software has been retained. *Seismosaic* is fully integrated with the seismic database and the waveform files.

The most complex and critical piece of the *Seismosaic* application is the *New Dataset* command. This command allows the user to create a dataset of sensor data from previous events that are similar to the impending event. It accomplishes this by querying the database for all event sources whose properties meet the criteria defined by the user.

Once the dataset has been created, a cross-tabulated report can be generated, which displays the selected amplitudes in a matrix by event name and amplitude name. This report is formatted in such a way that it can be easily imported into a spreadsheet program. After manually inserting yield values from previous seismic events into the spreadsheet, least-squares techniques are used to calculate the nuclear test yield.

For more information on *Seismosaic*, see Appendix C or the online help file that is provided in *Seismosaic*.

# Actions Taken to Document Procedures

Several documents have been provided to assist future analysts in determining the seismic yield. This SAND document provides the primary overview of what is available.

In terms of instructional documents, Doug Garbin has described the full procedure in a manual entitled *Seismic Yield Estimation Procedure*[1]. This manual and a user guide for *Seismosaic* are both available in an online help file that may be accessed from the help menu in *Seismosaic*.

Many other documents provide a record of the conversion process that took place. These exist as log files and are summarized in "readme" files or Excel spreadsheets.

The location of all of these documents is listed in Appendix D.

# Conclusions and Recommendations

To summarize the current state of the project, we have preserved geological properties, seismic waveforms, and associated P-wave amplitudes from 498 seismic events, which mostly resulted from underground nuclear detonations. This information has been organized into a new Microsoft Access® database, which may be retrieved directly through the Access application or through a new Windows-based application, *Seismosaic*. The primary purpose of *Seismosaic* is to facilitate the process of determining nuclear yields from seismic data. A manual has been written that describes this process.[1]

Since the beginning of this project, more than 20,000 amplitudes used in yield calculations have been converted from multiple files to a single table in the database. Approximately 3600 waveform files have been converted to a more readable format, with each file referenced by the database. Many of these waveform files were originally recorded in digital form, while several others had to be digitized from analog tape. During each conversion, extensive effort was made to validate and correct data anomalies.

The ASCII waveform files should easily have a shelf life of decades provided the storage media are kept current. The database, on the other hand, may need to be updated more frequently as newer versions of Access replace older versions. Converting to a database other than Access would require a significant modification to *Seismosaic*.

In the future, we should consider eliminating the need for a separate spreadsheet program and consolidate the least-squares functions directly into *Seismosaic*. We did not do it at this time because it was not part of the legacy (VAX) software and spreadsheet software is quite capable of handling these types of calculations. However, it would greatly simplify the seismic yield procedure to be able to complete it entirely in Seismosaic.

A final suggestion has been made that we completely change our method of determining yield and use digital signal analysis instead of scalar analysis. However, since we have only digitized 10% of the pre-1983 waveform data and we have a wealth of scalar amplitudes available to us, our top priority has been to preserve the current method. Additional methods or applications will be reserved for follow-on projects should the need arise.

## References

[1]H. D. Garbin, *Seismic Yield Estimation Procedure*, unpublished document.

[2]*United States Nuclear Tests, July 1945 Through September 1992*, DOE/NV-209 (Rev. 15), U. S. Department of Energy Nevada Operations Office, December 2000. URL: http://www.nv.doe.gov/news&pubs/publications/historyreports/pdfs/DOENV209_REV15.pdf [March 2001]

[3]*Radiological Effluents Released From U.S. Continental Tests 1961 Through 1992*, DOE/NV-317 (Rev. 1), U. S. Department of Energy Nevada Operations Office, August 1996.

[4]USGS National Earthquake Information Center, online information. URL: http://gldss7.cr.usgs.gov/neis/epic/*epic_circ.htm*. [March 2001]

# Appendix A – NTS Seismic Database

The legacy (VAX) system data was evaluated and a totally new relational database was designed and implemented in Microsoft Access® on the PC platform. Given the relatively small size of the database, Access® is a reasonable choice since it is site-licensed at Sandia and widely available elsewhere. It is also accessible to the *Seismosaic* application software through Visual C++.

The NTS Seismic database contains eight tables. Figure A-1 shows the tables, the number of records in each table, and the relationship between the tables.

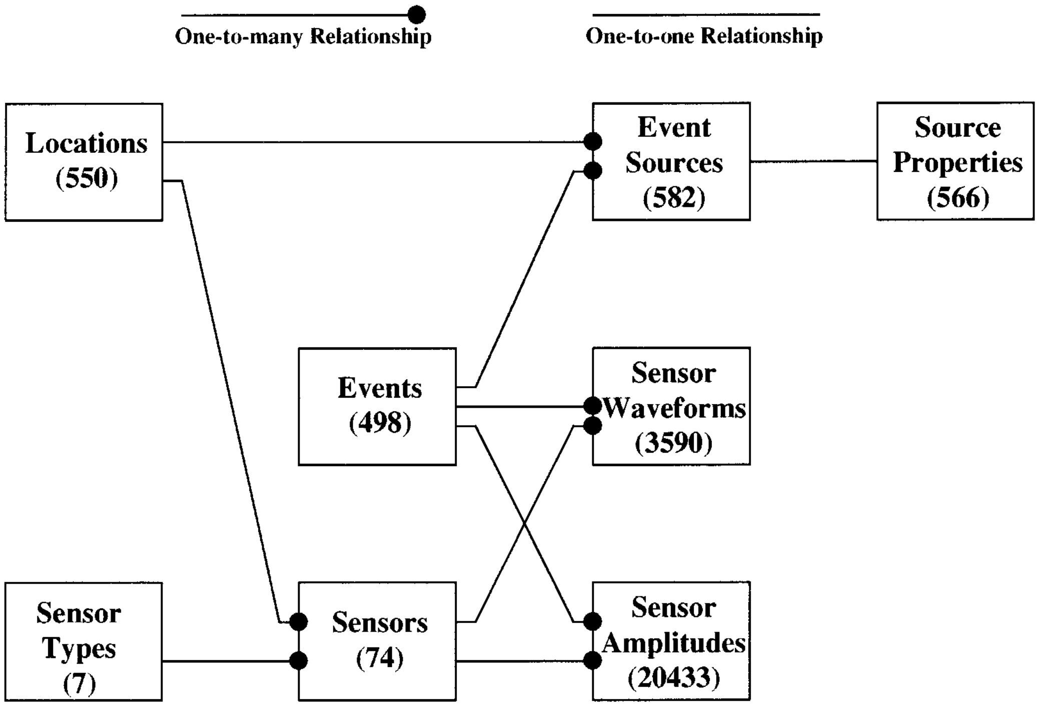



**Figure A-1, Database Tables**

The *Source Properties* table is a modification of the old physical properties table that existed as a flat file on the VAX™. The *Sensor Waveforms* table is similar to the waveform index table that was on the VAX™. It contains one record for each waveform data file. The new *Sensor Amplitudes* table essentially replaces all of the external amplitudes data files that were on the VAX™.

The other five tables were added to make the data less "flat" and more "relational." A relational database eliminates a lot of data duplication and also makes it possible to incorporate referential integrity to ensure that relationships between records in related tables are valid. Referential integrity is implemented by linking a unique field (primary key) from a primary table to the same field (foreign key) in a related table so that no value can be added to the related table without the same value being explicitly defined in the primary table. This reduces the likelihood of typos getting into the database. For example, data fields like *location* and *sensor* can now contain only those values that are explicitly defined in the new *Locations* and *Sensors* tables respectively.

Two important fields that are found in several tables are *Events* and *Sources*. *Event* is a common seismic term for any period of significant seismic activity. A detonation during a nuclear test would be one kind of event but not the only kind – an earthquake being an obvious example of another event. Because a single event is recorded for a period of time, multiple detonations or multiple nuclear tests within a short time period would be considered one seismic event – not multiple events.

To maintain precision in database terms, the word *event* should never be used to indicate a nuclear test or a detonation. Likewise, the word *test* should never be used to refer to a seismic event even though an event may in fact be the result of a single nuclear test. An event is designated by a year and a chronological sequence number. For example, event 8402 would be the 2$^{nd}$ seismic event of 1984.

A *source* is defined as the location where the seismic signal originated. In the NTS Seismic database, sources are always detonations. Sources from a nuclear detonation are identified by their DOE test/detonation name. Some nuclear tests had two or more detonations, therefore, each detonation of the nuclear test is listed separately (e.g., Kawich-Black and Kawich-Red).

Another important field that is used in several tables is *Sensor*. Sensors are typically designated by a four-character code (although this is not a requirement). The first character designates the station: B for Battle Mountain, D for Darwin, L for Leeds, N for Nelson, and T for Tonopah. The second character designates a component or direction: R for Radial, T for Tangential, V for Vertical, N for North, and E for East. The last two characters designate a code for the sensor type: GP for GS-13, SP for Benioff or 18-300, LP for SL-210 or SL-220, WB for NGC-23, and BH for Guralp. Sensor name TVGP would then be the vertical component of a GS-13 sensor at Tonopah.

All the fields for each table are shown in Figure A-2. Primary key fields are shown in Italics. Excerpts of each table can be found in Figures A-3 through A-8.

**Events**
- *Event*
- Date
- Time (GMT)
- Comments

**Event Sources**
- *Event*
- *Source*
- DOE Test No
- Location
- Date
- Time (GMT)
- Comments

**Source Properties**
- *Source*
- Surface Elev
- Burial Depth
- Aluv Tuff
- Tuff Pzoic
- Water Level
- Avg Density
- Avg Velocity
- WP Grain Dens
- WP Bulk Dens
- WP Velocity
- WP Gas Por
- WP Porosity
- WP Saturation
- Mag Body Wave
- WP Medium
- Comments

**Sensor Types**
- *Type*
- Code
- Mfgr
- Comments

**Sensors**
- *Sensor*
- Type
- Location
- Direction
- Recorder
- Comments

**Sensor Waveforms**
- *Event*
- *Sensor*
- Filename
- Date
- Time (GMT)
- TMin
- TMax
- Comments

**Sensor Amplitudes**
- *Event*
- *Sensor*
- *Amp Name*
- Amplitude
- Amp Units
- Comments

**Locations**
- *Location*
- Comments
- Coord System
- Latitude
- Longitude
- Elevation (m)
- Grid North (m)
- Grid East (m)

**Figure A-2, Database Tables and Fields**

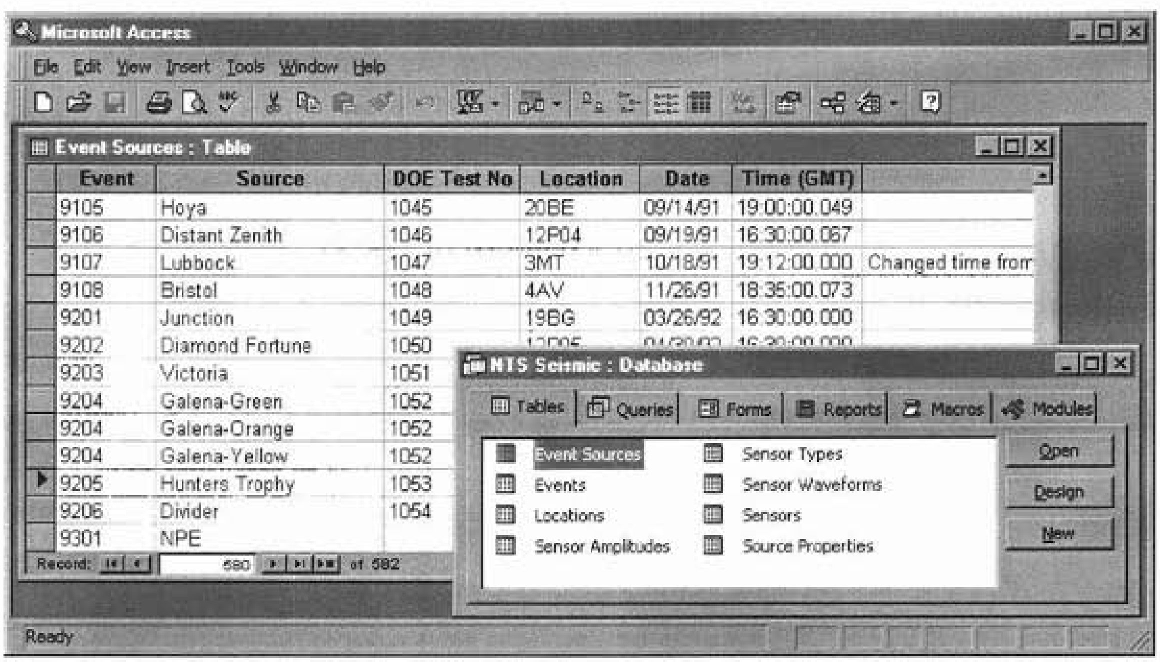
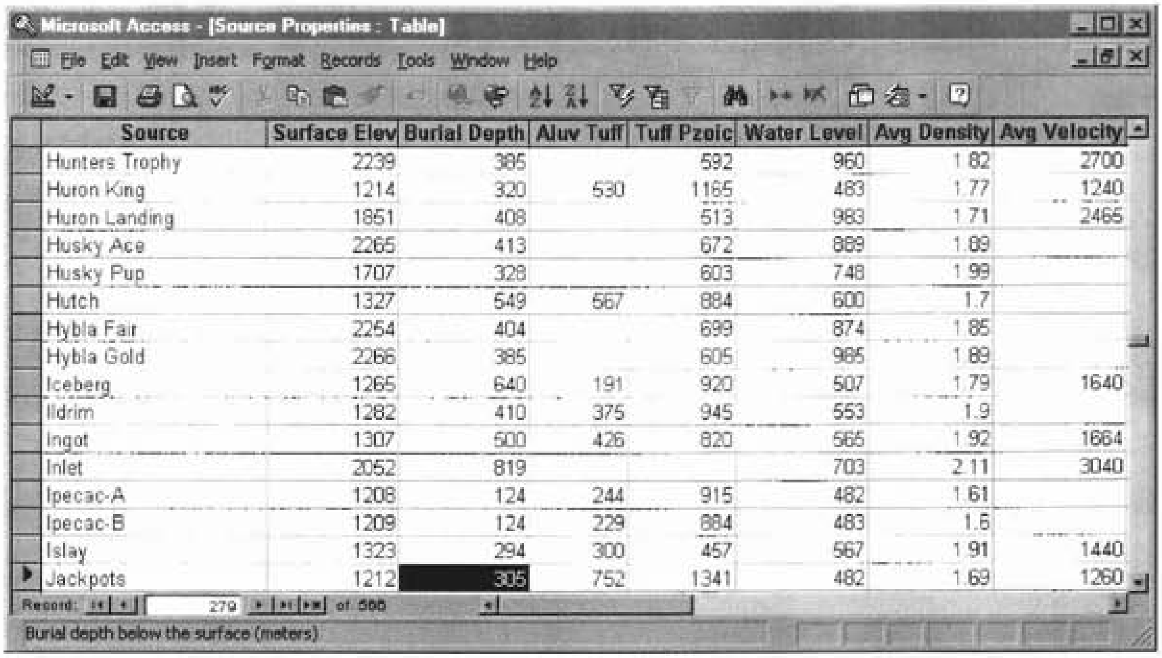



**Figure A-3, Event Sources Table**

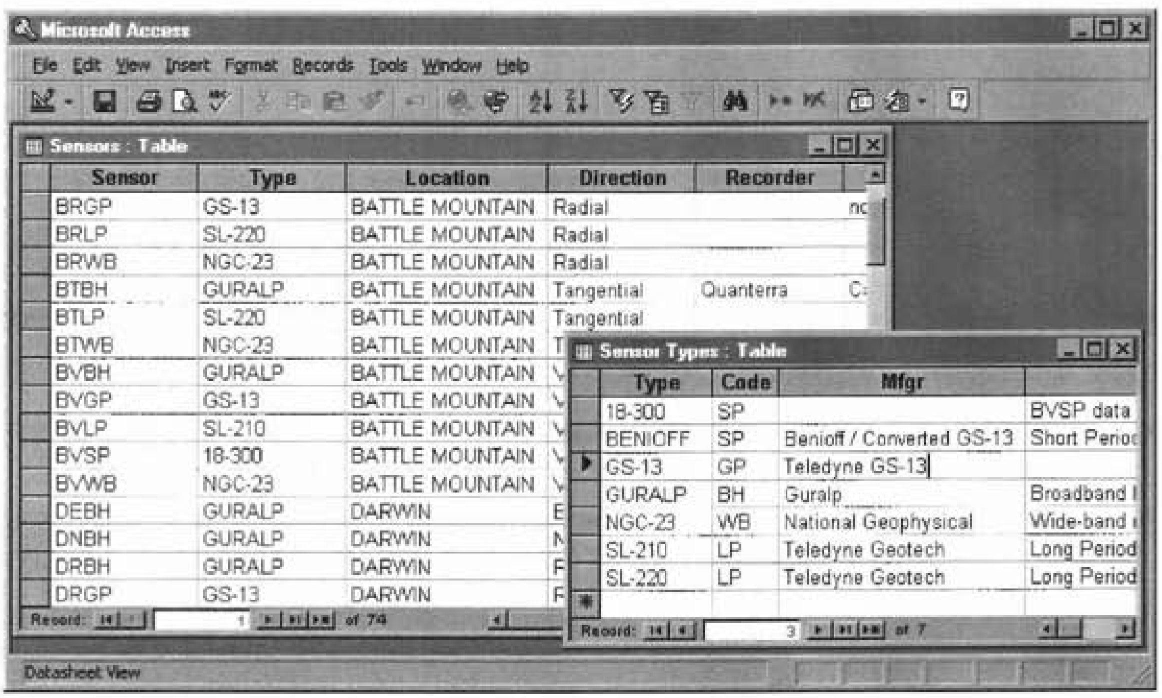




| Source | Surface Elev | Burial Depth | Aluv Tuff | Tuff Pzoic | Water Level | Avg Density | Avg Velocity |
|---|---|---|---|---|---|---|---|
| Hunters Trophy | 2239 | 385 | | 592 | 960 | 1.82 | 2700 |
| Huron King | 1214 | 320 | 530 | 1165 | 483 | 1.77 | 1240 |
| Huron Landing | 1851 | 408 | | 513 | 983 | 1.71 | 2465 |
| Husky Ace | 2265 | 413 | | 672 | 889 | 1.89 | |
| Husky Pup | 1707 | 328 | | 603 | 748 | 1.99 | |
| Hutch | 1327 | 549 | 567 | 884 | 600 | 1.7 | |
| Hybla Fair | 2254 | 404 | | 699 | 874 | 1.85 | |
| Hybla Gold | 2266 | 385 | | 605 | 985 | 1.89 | |
| Iceberg | 1265 | 640 | 191 | 920 | 507 | 1.79 | 1640 |
| Ildrim | 1282 | 410 | 375 | 945 | 553 | 1.9 | |
| Ingot | 1307 | 500 | 426 | 820 | 565 | 1.92 | 1664 |
| Inlet | 2052 | 819 | | | 703 | 2.11 | 3040 |
| Ipecac-A | 1208 | 124 | 244 | 915 | 482 | 1.61 | |
| Ipecac-B | 1209 | 124 | 229 | 884 | 483 | 1.6 | |
| Islay | 1323 | 294 | 300 | 457 | 567 | 1.91 | 1440 |
| Jackpots | 1212 | 305 | 752 | 1341 | 482 | 1.69 | 1260 |



Figure A-4, Source Properties Table





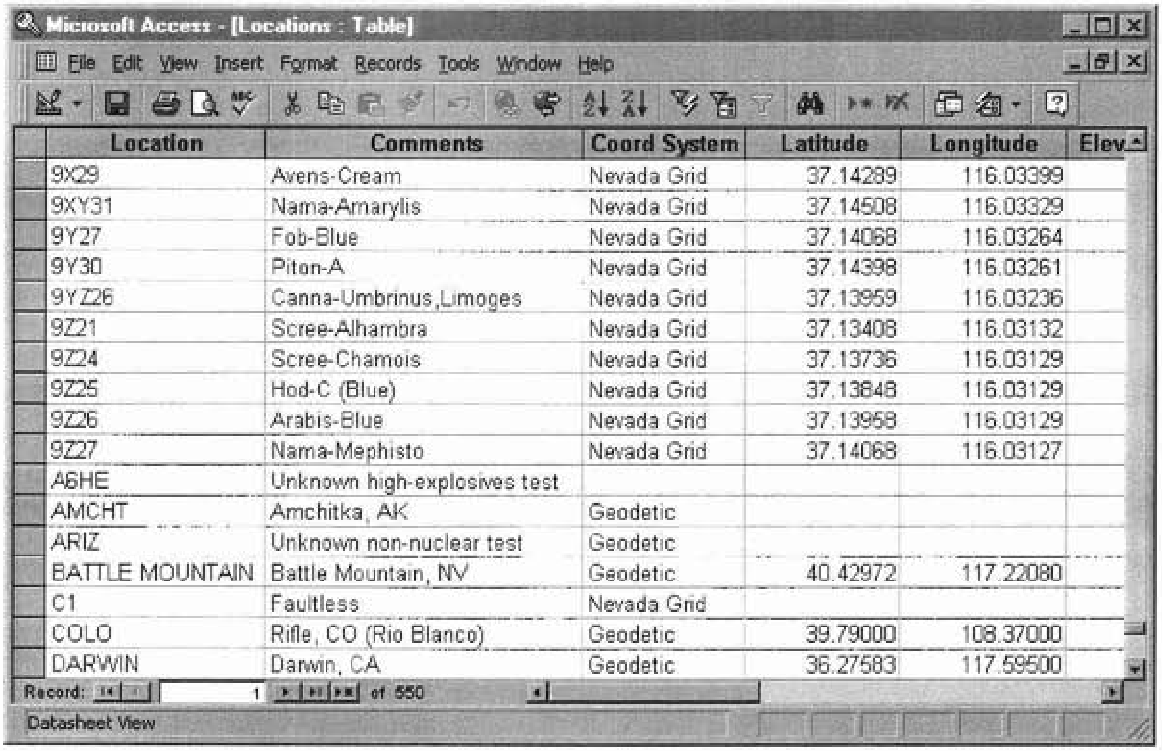
| Sensor | Type | Location | Direction | Recorder | |
|---|---|---|---|---|---|
| BRGP | GS-13 | BATTLE MOUNTAIN | Radial | | nc |
| BRLP | SL-220 | BATTLE MOUNTAIN | Radial | | |
| BRWB | NGC-23 | BATTLE MOUNTAIN | Radial | | |
| BTBH | GURALP | BATTLE MOUNTAIN | Tangential | Quanterra | C: |
| BTLP | SL-220 | BATTLE MOUNTAIN | Tangential | | |
| BTWB | NGC-23 | BATTLE MOUNTAIN | T | | |
| BVBH | GURALP | BATTLE MOUNTAIN | V | | |
| BVGP | GS-13 | BATTLE MOUNTAIN | V | | |
| BVLP | SL-210 | BATTLE MOUNTAIN | V | | |
| BVSP | 18-300 | BATTLE MOUNTAIN | V | | |
| BVWB | NGC-23 | BATTLE MOUNTAIN | V | | |
| DEBH | GURALP | DARWIN | E | | |
| DNBH | GURALP | DARWIN | N | | |
| DRBH | GURALP | DARWIN | F | | |
| DRGP | GS-13 | DARWIN | F | | |



| Type | Code | Mfgr | |
|---|---|---|---|
| 18-300 | SP | | BVSP data |
| BENIOFF | SP | Benioff / Converted GS-13 | Short Perioc |
| GS-13 | GP | Teledyne GS-13 | |
| GURALP | BH | Guralp | Broadband I |
| NGC-23 | WB | National Geophysical | Wide-band |
| SL-210 | LP | Teledyne Geotech | Long Period |
| SL-220 | LP | Teledyne Geotech | Long Period |



Figure A-5, Sensors and Sensor Types Tables



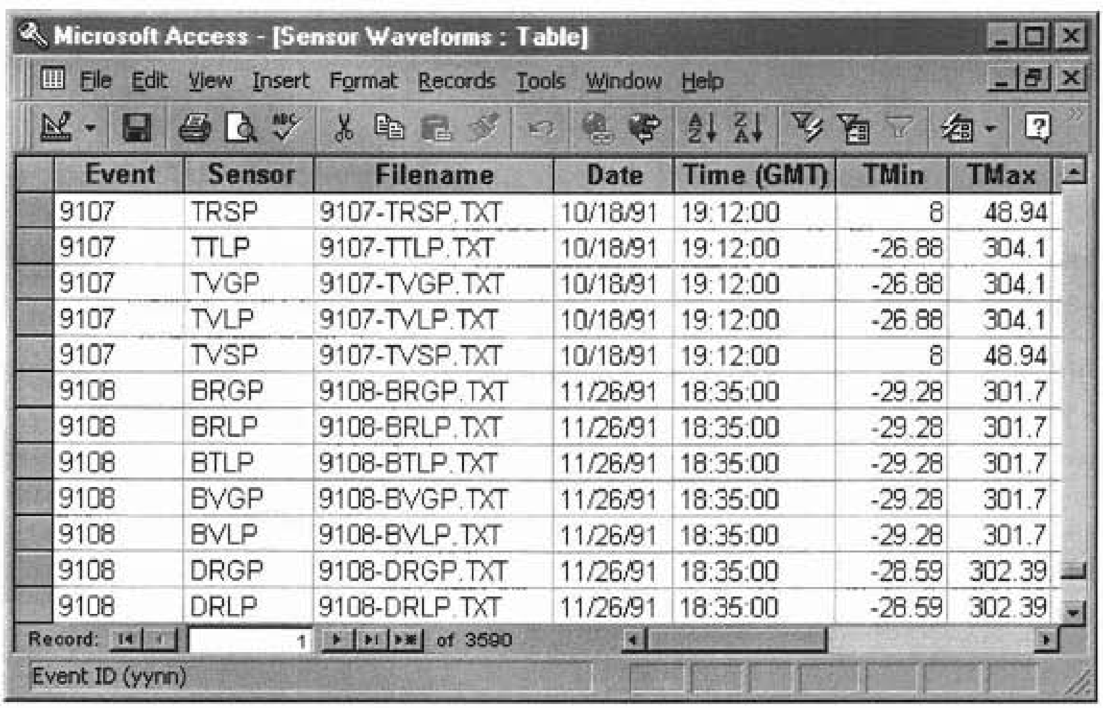
Microsoft Access - [Locations : Table]

| Location | Comments | Coord System | Latitude | Longitude | Elev. |
|---|---|---|---|---|---|
| 9X29 | Avens-Cream | Nevada Grid | 37.14289 | 116.03399 | |
| 9XY31 | Nama-Amarylis | Nevada Grid | 37.14508 | 116.03329 | |
| 9Y27 | Fob-Blue | Nevada Grid | 37.14068 | 116.03264 | |
| 9Y30 | Piton-A | Nevada Grid | 37.14398 | 116.03261 | |
| 9YZ26 | Canna-Umbrinus,Limoges | Nevada Grid | 37.13959 | 116.03236 | |
| 9Z21 | Scree-Alhambra | Nevada Grid | 37.13408 | 116.03132 | |
| 9Z24 | Scree-Chamois | Nevada Grid | 37.13736 | 116.03129 | |
| 9Z25 | Hod-C (Blue) | Nevada Grid | 37.13848 | 116.03129 | |
| 9Z26 | Arabis-Blue | Nevada Grid | 37.13958 | 116.03129 | |
| 9Z27 | Nama-Mephisto | Nevada Grid | 37.14068 | 116.03127 | |
| A6HE | Unknown high-explosives test | | | | |
| AMCHT | Amchitka, AK | Geodetic | | | |
| ARIZ | Unknown non-nuclear test | Geodetic | | | |
| BATTLE MOUNTAIN | Battle Mountain, NV | Geodetic | 40.42972 | 117.22080 | |
| C1 | Faultless | Nevada Grid | | | |
| COLO | Rifle, CO (Rio Blanco) | Geodetic | 39.79000 | 108.37000 | |
| DARWIN | Darwin, CA | Geodetic | 36.27583 | 117.59500 | |

Record: 1 of 550

Datasheet View

**Figure A-6, Locations Table**



Microsoft Access - [Sensor Waveforms : Table]

| Event | Sensor | Filename | Date | Time (GMT) | TMin | TMax |
|---|---|---|---|---|---|---|
| 9107 | TRSP | 9107-TRSP.TXT | 10/18/91 | 19:12:00 | 8 | 48.94 |
| 9107 | TTLP | 9107-TTLP.TXT | 10/18/91 | 19:12:00 | -26.88 | 304.1 |
| 9107 | TVGP | 9107-TVGP.TXT | 10/18/91 | 19:12:00 | -26.88 | 304.1 |
| 9107 | TVLP | 9107-TVLP.TXT | 10/18/91 | 19:12:00 | -26.88 | 304.1 |
| 9107 | TVSP | 9107-TVSP.TXT | 10/18/91 | 19:12:00 | 8 | 48.94 |
| 9108 | BRGP | 9108-BRGP.TXT | 11/26/91 | 18:35:00 | -29.28 | 301.7 |
| 9108 | BRLP | 9108-BRLP.TXT | 11/26/91 | 18:35:00 | -29.28 | 301.7 |
| 9108 | BTLP | 9108-BTLP.TXT | 11/26/91 | 18:35:00 | -29.28 | 301.7 |
| 9108 | BVGP | 9108-BVGP.TXT | 11/26/91 | 18:35:00 | -29.28 | 301.7 |
| 9108 | BVLP | 9108-BVLP.TXT | 11/26/91 | 18:35:00 | -29.28 | 301.7 |
| 9108 | DRGP | 9108-DRGP.TXT | 11/26/91 | 18:35:00 | -28.59 | 302.39 |
| 9108 | DRLP | 9108-DRLP.TXT | 11/26/91 | 18:35:00 | -28.59 | 302.39 |

Record: 1 of 3590

Event ID (yynn)

**Figure A-7, Sensor Waveforms Table**

Microsoft Access - [Sensor Amplitudes : Table]

| Event | Sensor | Amp Name | Amplitude | Amp Units |
|---|---|---|---|---|
| 9004 | NVLP | VA | 0.000164824 | CM/SEC |
| 9004 | TRGP | RA | 0.00021932901 | CM/SEC |
| 9004 | TRGP | RP | 0.0048969002 | CM/SEC |
| 9004 | TRLP | RA | 0.00047469302 | CM/SEC |
| 9004 | TRSP | RA | 0.353605 | MICRONS |
| 9004 | TRSP | RP | 9.8479004 | MICRONS |
| 9004 | TVGP | VA | 0.00049231102 | CM/SEC |
| 9004 | TVGP | VB | 0.0015942501 | CM/SEC |
| 9004 | TVGP | VP | 0.0062107998 | CM/SEC |
| 9004 | TVLP | VA | 0.0010132251 | CM/SEC |
| 9004 | TVLP | VB | 0.0018398 | CM/SEC |
| 9005 | BRGP | RA | 2.6270005E-05 | CM/SEC |

Record: 1 of 20433

Event ID

**Figure A-8, Sensor Amplitudes Table**

# Appendix B – Conversion and Data Validation

There were four phases to converting VAX™ data to the Windows® 2000 platform. Each phase involved not only converting data formats, but also validating the data through crosschecks to ensure internal consistency.

The first phase was to populate the new Access® database by importing the physical properties database and manually entering the missing information from external documents.[2,3,4] The second phase was to insert the P-wave amplitudes from the VAX™ files into the *Sensor Amplitudes* table of the database. The third phase was to convert the digital waveforms that existed on the VAX™ to a more readable format. The fourth phase was to convert the analog waveform data to the same format as the other waveforms. Each phase is described in detail below.

## Phase 1: Database Population

After the database was designed, parts of it were populated manually from external documents[2,3,4] and other parts were populated by software that was written specifically for that task.

The first step in populating the database was to import the VAX™ properties file and the VAX™ waveforms table into Microsoft Access® tables and then use that data to build a preliminary version of the *Events* table, *Source Properties* table, *Locations* table, and *Sensor Waveforms* table.

The next step was to manually enter the Leo Brady Seismic Network information into the *Locations* table and two new tables – the *Sensor Types* table and *Sensors* table. This was done to provide referential integrity to locate typos in the data. At the same time, the *Event Sources* table was manually built partially from information in the *Events* table and partially from information contained in external DOE and USGS documents.[2,3,4]

The last two steps were to populate the *Sensor Amplitudes* table and update the *Sensor Waveforms* table during the conversion processes described in Phase 2 and Phase 3.

Throughout the conversion period, a lot of inconsistencies in the old data had to be resolved. A lot of research into historical documents[2,3,4] was required to repair the data, particularly in matching tests with events and assigning the correct locations and times to the proper source detonations. The historical documents were often in disagreement with our data – as well as with each other! However, with multiple sources of information and a little common sense, it was almost always possible to determine which values were correct and which were typos. While the information in the database is far from complete (especially the *Source Properties* table), it is now internally consistent and much closer to being error-free than it was previously.

## Phase 2: Amplitudes Conversion

Approximately 13700 P-wave amplitudes were measured by hand from seismograph strip charts during the period from 1969 to 1982. From 1983 to 1993 another 6166 amplitudes were added either manually or by using software written by Doug Seastrand on the VAX™. The 25 files containing these amplitudes (one file for each year) were moved from the VAX™ to the Windows® 2000 server.

Two similar programs (in *Seismosaic*) were written to read the VAX™ amplitudes files and insert the amplitudes records into the *Sensor Amplitudes* table of the NTS Seismic database. The primary difference in the two programs is a change of format that occurred in 1987.

Each of the above programs performed several checks on the amplitudes records to validate the data before inserting it into the database. If a record did not pass every check, it was "kicked out" into a log file for further analysis. The kick-outs included numerous unmatched locations and sensors (usually typos), 520 duplicate records, amplitudes with no ID (usually 0.0), and other miscellaneous problems.

After making the first pass through all the files, the kick-outs were researched and corrections were made where possible. Then the *Sensor Amplitudes* table was cleared and a second pass was made through the data. This pass reinserted the amplitudes into the table and generated a final set of log files containing the duplicate records and unidentified amplitudes that could not be inserted into the database. These final anomalies are summarized in the "Amp conversion" sheet in the Excel file *Data Anomalies.xls*. (See Appendix D for the location of this file and the log files.)

All amplitudes are now stored in the database, not in files. Additional amplitudes have been added to the database for the events in 1966-1968 that were recently digitized by Gary Vines. Curtis Harmon did this recently using the *Seismosaic* capability to plot waveforms and interactively measure amplitudes. A log was kept by Curtis and is stored in file *event66-68.log*. (See Appendix D for the location of this file.)

## Phase 3: Digital Waveform Conversion

A data validation and conversion program was written to convert VAX™ files (also known as "final-tape" files) to a more readable format for the Windows platform.

Because most of the header information in the final-tape files is also in the seismic database, an opportunity was taken to crosscheck the header information with the database to determine where discrepancies occurred and to ensure internal consistency of the data. In particular, all location names, location coordinates, dates, times, and source properties were checked by scanning software that was developed specifically for this task.

Specific problems that were discovered and the solutions are described in the file *Conversion Summary.doc.* A more complete list of encountered problems and solutions is provided in an Excel spreadsheet in file *Data Anomalies.xls.*

After making several passes through the waveform files with the data validation software to resolve discrepancies between the header and database, the code was prepared for a final pass to write new files with the corrections. The data conversion accomplished several things.

First, the file format was improved by making the new format self-documenting. To do this, we replaced the original header containing fields of specific location and width with a header that contains named variables in the form *keyword=value*. By using keywords, we no longer need an external document to know the name and location of each data field and the data is far less susceptible to accidental corruption.

A *Notes* section follows the keyword section of the file. This section contains any comments up to the size of a novel. The *Data* section follows the *Notes* section. It consists of six required keywords followed by a single column of waveform samples. A partial example of the new waveform format is shown in Figure B-1.

```
BEGIN KEYWORDS
Event=8305
Date=04/22/83
GMTime=13:53:00
Source=Armada
Source Loc=9CS
Source Lat=37.111517
Source Long=116.02243
Sensor=TVSP
Sensor Loc=TONOPAH
Sensor Type=BENIOFF
Sensor Dir=Vertical
   :

BEGIN NOTES
Inserted 8 sample(s) between -25.070 and -24.890.
Inserted 6 sample(s) between -15.910 and -15.770.
Inserted 12 sample(s) between -13.790 and -13.530.
   :

BEGIN DATA
NAME=8305-TVSP
XLABEL=Seconds
YLABEL=MICRONS
POINTS=22444
X0=-29.050
DX=0.020
 2.05688e-003
 2.06018e-003
 2.05194e-003
 2.04534e-003
   :
```

**Figure B-1, Waveform File Example**

In addition to concerns about the header format, there were concerns about the waveform samples themselves. Specifically, 95% of the "final-tape" files did not contain uniformly sampled data (i.e., the values of the X array did not have a constant interval between them). This was usually due to data lost in transmission ("dropouts"), but in some cases the sample interval briefly changed to half the normal interval, and in other cases the interval was actually negative!

While it is possible to plot data without a uniform X array, it is not possible to apply digital signal processing techniques. This is important because we need to apply a transfer function to recent GS-13 sensor data in order to compare it accurately to older Benioff data (with a different frequency response).

To correct the "dropout" problem, an algorithm was developed to interpolate gaps that exceeded 1 sample interval and shift data when the sample interval was negative or ½ the normal interval. The algorithm performed a checksum between the number of samples expected (based on the specified $X_{min}$ and $X_{max}$ values) vs. the number of samples that were actually read. The checksum also accounted for the number of samples lost at the beginning and end of the waveform, the extra samples not expected at the beginning and end, and the samples that were inserted via interpolation.

The major assumption of the algorithm is that the $X_{min}$ and $X_{max}$ values that were specified in the original data file were accurate prior to transmission of the data. Thankfully, that was the case, as we were able to convert 100% of the files to uniformly sampled data without a single checksum failure.

A side benefit of converting the data to a constant sample interval is that we no longer need to store the entire X array, which reduces the file size by approximately 40%.

One final thing that was accomplished as a result of the file conversion was a change in the file name. By changing the name from <sensor><event>*.txt* to <event>-<sensor>*.txt*, we now get the desired chronological sorting order by event when displaying the files in a folder.

## Phase 4: Analog Waveform Conversion

Seismic data was not digitally recorded until 1983. Before then it was recorded on analog tape as well as seismograph strip-charts. In 1999, Gary Vines (contractor to Bechtel) generated digital data from the analog tapes of 45 events (mostly from high-yield tests). This binary-formatted data is stored on CDs in 5 notebooks entitled "Mag Tape Archive Project." One copy exists at the U.S. Department of Energy National Nuclear Security Administration Nevada Operations Office in Las Vegas, Nevada. The other copy is at Sandia in building 962, Room 1069B.

Jonathan Lee and Curtis Harmon converted the binary data on the CDs to *Seismosaic* waveform files during the summer of 2001. The conversion process took two steps. The first step was to convert the data to counts in the *Seismosaic* format. The second step was to calibrate the data by using the graphics tools in Seismosaic to measure the calibration pulses at the front of the waveform and then enter the cal factor information from seismic field sheets. The conversion and calibration programs are both part of the *Seismosaic* application and could be used again if needed.

Most sensors were recorded at different sensitivity levels (e.g., "divide by 5" and "divide by 25") to provide alternate waveforms so that at least one waveform would have a reasonable signal-to-noise ratio without being clipped.

Only the short period channels ("RSP", "TSP", and "VSP") were converted because they provide a much better representation of the P-wave than either long period or wide band channels. Historically, yield estimation was accomplished exclusively with the short period channels. The long period and wide-band channels were used primarily for discrimination studies that enhanced our ability to distinguish between earthquakes and explosions.

Of the 1208 short-period waveforms that were converted to counts, only the 449 primary ("divide by 1") waveforms were calibrated. (Actually, 23 could not be calibrated and are probably unusable.) The other 759 waveforms are available in counts as alternate waveforms. If at some time in the future a primary waveform is deemed to be unusable, it may be replaced by one of the alternate waveforms after the alternate is calibrated.

# Appendix C – *Seismosaic* Application

*Seismosaic* is a Windows® application that was designed by Jonathan Lee to handle all the preliminary steps of yield determination that were formerly done with the VAX™ software. (The VAX™ software was called "PHY" for its ability to select data from the **phy**sical properties database.)

Before designing *Seismosaic*, Jonathan created a system data flow diagram of PHY by reading the documentation that could be found and by interviewing Doug Seastrand, who wrote PHY. After the initial diagram was created and reviewed by Doug, a new data flow diagram was created for a new software system that incorporates the data migration paths from the VAX system to Windows.

The new data flow diagram is shown in Figure C-1. The rectangles and "drums" represent data objects. The ellipses represent functions that were developed in *Seismosaic* to process the data. The dotted lines represent data sources and functions that are no longer needed on the new platform. (However, both the data and code are still available in case a problem with the conversion process is discovered in the future.)

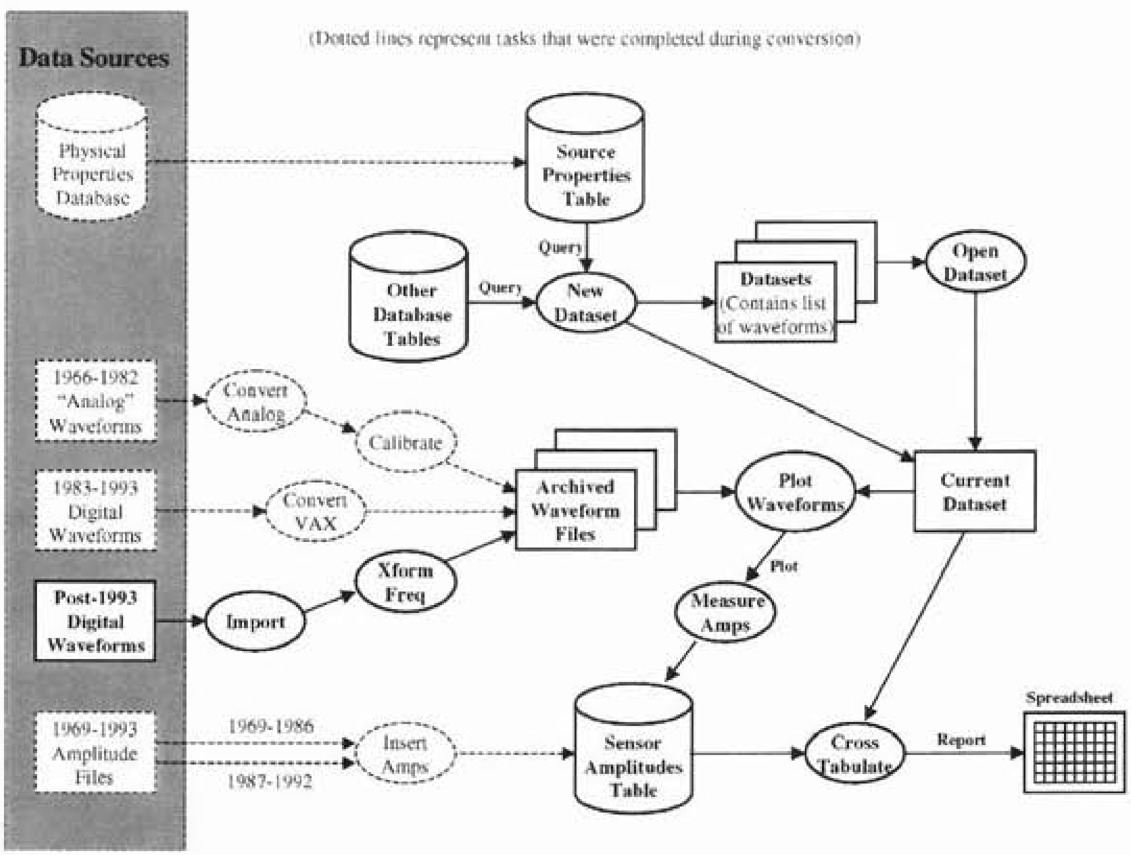



**Figure C-1,** ***Seismosaic*** **Data Flow**

The *Seismosaic* user interface is designed with a split screen. (See Figure C-2.) A list of waveforms in the current dataset is displayed to the left of a graphics window. When a waveform is selected from the list, it is plotted automatically.

There are two cursor functions available with the graphics. Zoom-in is available by clicking the left mouse button on one corner of the zoom window and dragging the cursor to the opposite corner. Amplitudes can be measured by clicking the right mouse button on one point and dragging the mouse to the other point. This will display an I-beam and popup a dialog box with the exact measurement. The user will then have the option to label the amplitude and save it in the *Sensor Amplitudes* table.

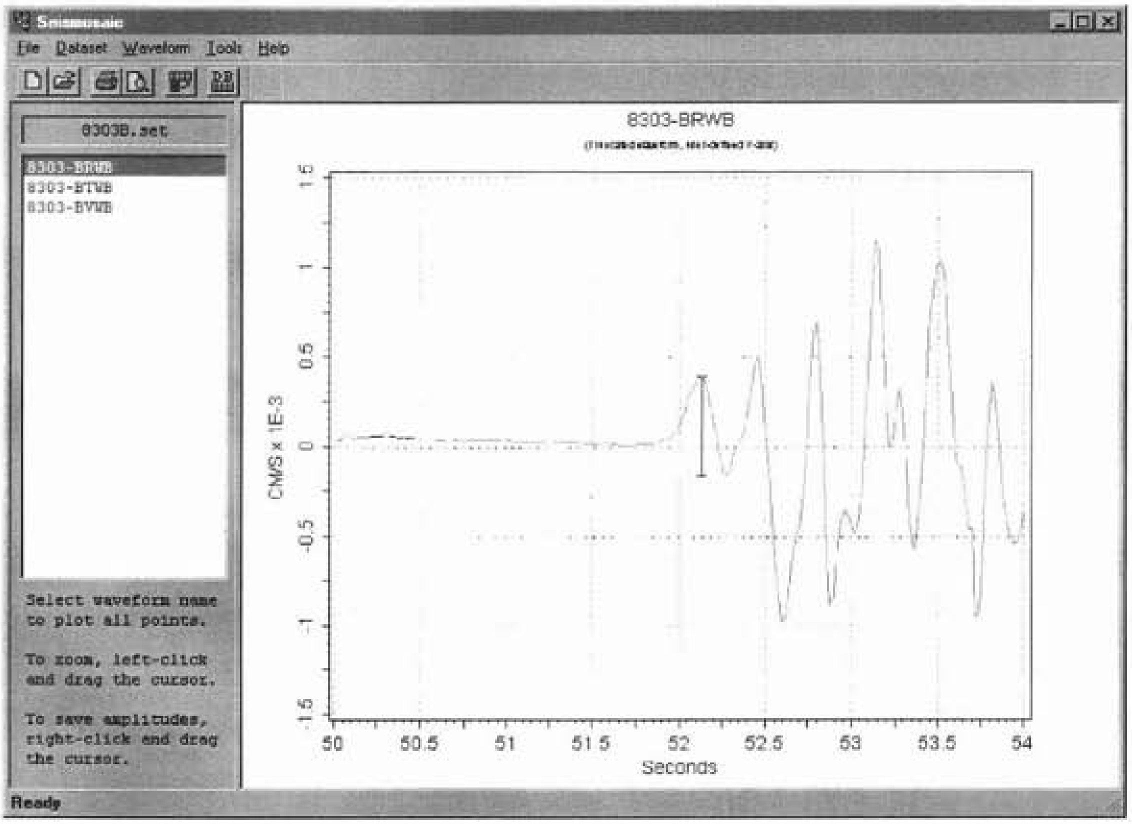



**Figure C-2, *Seismosaic* User Interface**

If an amplitude with this label already exists in the database for the given event and sensor, the operator will be asked to verify whether or not to replace it with the new amplitude. If he or she chooses to replace the amplitude, the original will be saved in the comment field of the record.

Other functions in *Seismosaic* are initiated from the dropdown menus or toolbar. **Print Preview** and **Print** are available for displaying a preview and making a hardcopy of the plot window. **Seismic Database** is available on the **Tools** menu for direct access to the NTS Seismic database through the Microsoft Access® application.

A new dataset is created via the **New Dataset** command on the **File** menu. This command pops up a dialog box (shown in Figure C-3) with fields for querying the database properties. The query will produce a set of sensor waveforms for events with properties that match the specified criteria.

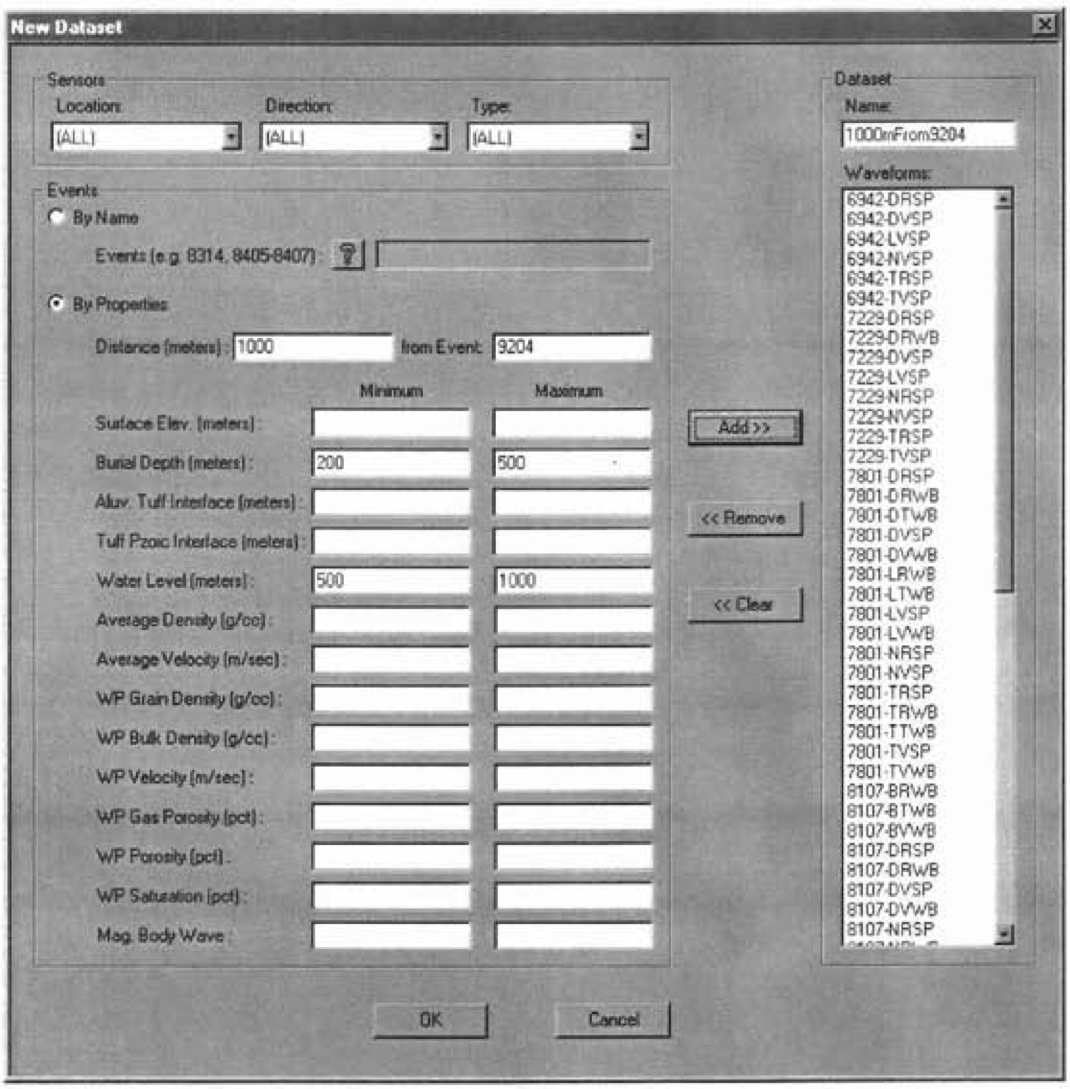



**Figure C-3, Creating a New Dataset**

The selection criteria on the left side of the dialog are divided into "Sensors" and "Events" with "Events" subdivided into "By Name" or "By Properties." The query algorithm combines the selection criteria with a Boolean AND. To use a Boolean OR, one simply uses the **Add** button multiple times until the dataset is completed.

Once a dataset has been created, it can be reopened at a later time with the **Open Dataset** command on the **File** menu.

After a dataset has been selected by one of the **File** commands, the **Cross-tab Amplitudes** command will create a report of all amplitudes for the events represented in the current dataset. Amplitudes will be tabulated by rows of sensors and amplitude names and columns of event names for easier comparison. (For readers that are unfamiliar with database lingo, cross-tabulation is a database function similar to matrix transposition.)

The report will be displayed in a Notepad window, from which it may be printed. (See Figure C-4.) Later the report can be imported into a spreadsheet program for doing the final seismic yield calculation using the hand-entered seismic yields from each historical event in the dataset. This final step is done offline to avoid making Seismosaic classified.

500mFrom7207.xtab - Notepad

File Edit Search Help

Amplitudes crosstab report for all events in dataset 500mFrom7207

| Sensor | Amp Name | Amp Units | 7117 | 7207 | 7212 | 7227 | 7415 | 7614 |
|---|---|---|---|---|---|---|---|---|
| BRWB | RP | CM/SEC | | 0.000529 | | | | |
| BRWB | RPN | CM/SEC | | | 0.000171 | 0.000221 | | |
| BTWB | TPG | CM/SEC | | | | | 0.000288 | |
| BUWB | VB | CM/SEC | | 6.6e-005 | 0.0001 | | | |
| BUWB | VC | CM/SEC | | 9e-005 | 0.000118 | | | |
| BUWB | VD | CM/SEC | | 9.4e-005 | 0.00014 | | | |
| BUWB | VP | CM/SEC | | 0.000629 | | 0.0009 | | |
| BUWB | VPG | CM/SEC | | | | | 0.000392 | |
| BUWB | VPN | CM/SEC | | 0.00025 | 0.00023 | 0.000294 | 0.00018 | |
| DRSP | R1 | MICRONS | | 0.999 | 1.38 | 1.6 | | 15.5 |
| DRSP | R2 | MICRONS | | 1.9 | 2.56 | 3.26 | | |
| DRSP | R3 | MICRONS | | | | 3.31 | | |
| DRSP | RA | MICRONS | | | 0.103 | | | 1.22 |
| DRSP | RB | MICRONS | | | | 0.57 | | 4.77 |
| DRSP | RP | MICRONS | | 2.19 | 3.05 | 3.31 | | 22.4 |
| DRSP | RS | MICRONS | | 2.33 | 4.14 | 2.74 | | |
| DRWB | R1 | CM/SEC | | 0.001082 | 0.001752 | 0.001428 | 0.000871 | |
| DRWB | R2 | CM/SEC | | 0.001469 | | 0.002342 | | |
| DRWB | RA | CM/SEC | | 0.000139 | 0.000189 | | | 0.002622 |
| DRWB | RB | CM/SEC | | | | 0.000511 | | 0.01228 |
| DRWB | RC | CM/SEC | | | | | | 0.0195 |
| DRWB | RP | CM/SEC | | 0.001469 | 0.002085 | 0.002342 | 0.00099 | 0.0195 |
| DRWB | RS | CM/SEC | | | 0.00279 | | | |
| DTWB | TP | CM/SEC | | | | | 0.000615 | |
| DUSP | V1 | MICRONS | | 1.15 | 1.42 | 1.89 | 0.78 | 11.7 |
| DUSP | VA | MICRONS | | | 0.0768 | | | 1.02 |
| DUSP | VB | MICRONS | | | | 0.451 | | 3.93 |
| DUSP | VC | MICRONS | | 0.736 | 0.979 | 1.16 | | 9.23 |
| DUSP | VP | MICRONS | | 1.5 | 1.82 | 2.19 | | 11.7 |
| DUSP | VS | MICRONS | | 2.52 | | 2.13 | 1.62 | |

**Figure C-4, Cross-tabulation of P-wave Amplitudes in a Dataset**

The *Seismosaic* **Tools** menu contains the conversion and calibration utilities that were written for the sole purpose of migrating data from the VAX™. They will remain there in case the conversion procedure unexpectedly needs to be modified and redone.

An installation procedure has been written for *Seismosaic* using InstallShield® for Visual C++. The location of the installation files is described in Appendix D.

For further information on *Seismosaic*, see the online help file.

# Appendix D – Inventory of System Files

This appendix provides a full inventory of the files related to NTS seismic data. The first section describes the organizational structure of the files. The second section describes the location of the repositories where the files are stored.

## Directory Structure

The root directory – "NTS Seismic" – contains 4 folders with active data and 1 folder with historical data. The 4 active folders are Database, Docs, Seismosaic, and Waveforms. The remaining folder is entitled Preservation Project. The contents of the folders in the root directory are shown in table D-1. The contents of the Seismosaic folder and Preservation Project folder are shown in tables D-2 and D-3 respectively.

| Folder | Contents | # Files | Size (MB) |
|---|---|---|---|
| NTS Seismic | Root directory | 14,565 | 4961 |
| Docs | Documentation files | 9 | 4 |
| Preservation Project | All historical files that were migrated from the VAX and files related to their conversion to PC | 10,816 | 3060 |
| Seismosaic | Visual C++ code, docs, and installation procedures for *Seismosaic* software | 148 | 17 |
| Waveforms | Current waveform data files + a 392MB Zip file of all the waveforms | 3592 | 1880 |

**Table D-1. NTS Seismic Files**

Each major folder contains a *_Readme.txt* file that describes the contents of the folder in more detail. Several subfolders also contain *_Readme.txt* files.

| Folder | Contents | # Files | Size (MB) |
|---|---|---|---|
| Seismosaic | Visual C++ code, docs, and installation procedures for *Seismosaic* software | 148 | 16.8 |
| Database | NTS Seismic.mdb and its backup (both Microsoft Access databases) | 2 | 5.7 |
| Debug | Executable file for debug mode | 1 | .4 |
| Help | Files and images needed to create the online help file with Microsoft HTML Help Workshop | 20 | .4 |
| Installation | Installation files created by Installshield® for three media types: CD, diskettes, and download | 61 | 9.5 |
| Release | Executable file for release mode | 1 | .2 |
| res | Resource files | 7 | ~ |

**Table D-2. Seismosaic Files**

When *Seismosaic* is installed (by executing the Setup.exe file on the selected media), it will create a new folder on the computer of the *Seismosaic* user. By default, this folder is c:\Program Files\Sandia\Seismosaic. This folder contains the *Seismosaic* executable, help file, database, and a subfolder for storing user-defined datasets.

| Folder | Contents | # Files | Size (MB) |
|---|---|---|---|
| Preservation Project | Files that were migrated from the VAX and files related to the conversion to PC | 10,816 | 3060 |
| Amplitudes (1966-1993) | VAX amplitudes files and 2 sets of conversion log files | 138 | 18 |
| Analog Waveforms (1966-1982) | Intermediate "counts" files that were converted but not calibrated | 1192 | 1890 |
| Digital Waveforms (1983-1993) | VAX digital waveforms ("final-tape") and 2 sets of conversion log files | 9448 | 1140 |
| Old VAX Programs | Software utilities and documentation that were used on the VAX | 15 | 2.4 |
| Project Reports | Status reports and viewgraphs used from 1999-2001 | 20 | 4.6 |

**Table D-3. Preservation Project Files**

The following is a list of the files that were referenced in the document and their directory locations:

| | |
|---|---|
| Data Anomalies.xls | \NTS Seismic\Preservation Project\ |
| Conversion Summary.doc | \NTS Seismic\Preservation Project\Digital Waveforms |
| Event66-68.log | \NTS Seismic\Preservation Project\Amplitudes |
| Setup.exe (install file) | \NTS Seismic\Seismosaic\Installation\CD-r |

## Repositories

The primary caretaker for the above files is the Instrumentation Development Department. All the directories and files described in the previous sections are currently stored on a Windows 2000 server.

By written formal request, a CD may be obtained that contains all of the above files except for the Preservation Project files. However, the waveform files will be stored in a compressed ZIP file in order to get them all on one CD. To access these files through *Seismosaic*, they must first be extracted onto a hard disk. This should be done before installing *Seismosaic* so that the directory can be specified during the installation procedure.

In the future, the NTS Seismic files may be moved or added to additional repositories in order to make them more accessible from outside Sandia. For up-to-date information on file locations, contact the author at jwlee@sandia.gov.

DISTRIBUTION:

4 U.S. Doe/NNSA/NV
Attn: Steve Leedom
Timothy McEvoy
Technical Information Resource Center
DOE NNSA/NV Public Reading Facility
P.O. Box 98518
Las Vegas, NV 89193-8518

4 Bechtel Nevada, NLV075
Attn: Steve Becker
Michael O'Connor
Gary Vines
Bob White
P.O. Box 98521
Las Vegas, NV 89193-8521

2 Los Alamos National Laboratory
Attn: Howard Patton, MS D408
Stephen R. Taylor, MS D408
P.O. Box 1663
Los Alamos, NM 87545-0001

3 Lawrence Livermore National Laboratories
Attn: Keith Nakanishi, MS L-205
William Walter, MS L-205
John J. Zucca, MS L-205
P.O. Box 808
Livermore, CA 94551-0808

1 Lamont Doherty Earth Observatory
Attn: Paul G. Richards
Earth and Environmental Science Dept.
Columbia University
Palisades, NY 10964

1 University of Arizona
Attn: Terry C. Wallace
Dept. of Geosciences
Gould Simpson Bldg #77
Tucson, AZ 85721

1 Maxwell Technologies
Attn: John R. Murphy
11800 Sunrise Valley Drive Ste 1212
Reston, VA 20191-5302

1 Center for Monitoring Research
Attn: Keith McLaughlin
1300 N. 17$^{th}$ Street Ste 1450
Arlington, VA 22209

2 University of Nevada
Attn: David Von Seggern
Ken Smith
Seismological Lab MS 174
1664 N. Virginia St.
Reno, NV 89557

1 Defense Threat Reduction Agency
Attn: Robert Reinke
1680 Texas Street SE
Kirtland AFB, NM 87117-5665

1 Southern Methodist University
Attn: Brian Stump
Department of Geological Sciences
Dallas, TX 75275-0395

| | | |
|---|---|---|
| 1 | 0136 | P. A. Raglin, 9721 |
| 1 | 0482 | B. C. Bedeaux, 2109 |
| 1 | 0633 | W. B. Boyer, 2952 |
| 1 | 0750 | M. C. Walck, 6116 |
| 1 | 0859 | T. K. Stalker, 15351 |
| 1 | 0975 | E. P. Chael, 5736 |
| 1 | 0975 | P. B. Herrington, 5736 |
| 1 | 1156 | R. D. M. Tachau, 15322 |
| 1 | 1159 | W. H. Barrett, 15344 |
| 1 | 1159 | A. J. Chabai, 15344 |
| 1 | 1159 | K. M. Glibert, 15344 |
| 1 | 1159 | M. A. Hedemann, 15344 |
| 1 | 1168 | R. Abbott, 1612 |
| 1 | 1168 | C. Deeney, 1612 |
| 1 | 1168 | H. D. Garbin, 1612 |
| 15 | 1168 | J. W. Lee, 1612 |
| 1 | 1170 | R. M. Clancy, 15309 |
| 1 | 1170 | L. Livingston, 15309 |
| 1 | 1170 | R. W. O'Rourke, 15309 |
| 1 | 1181 | J. R. Asay, 1610 |
| 1 | 1190 | J. P. Quintenz, 1600 |
| 1 | 1391 | M. E. Burke, 1614 |
| 1 | 1391 | W. J. Kluesner, 1614 |
| 1 | 1391 | D. S. Nelson, 1614 |
| 1 | 1391 | D. D. Thomson, 1614 |
| 1 | 1391 | R. C. Shear, 15322 |
| 1 | 9018 | Central Technical Files, 8945-1 |
| 2 | 0899 | Technical Library, 9616 |
| 1 | 0612 | Review and Approval Desk, 9612 (For DOE/OSTI) |